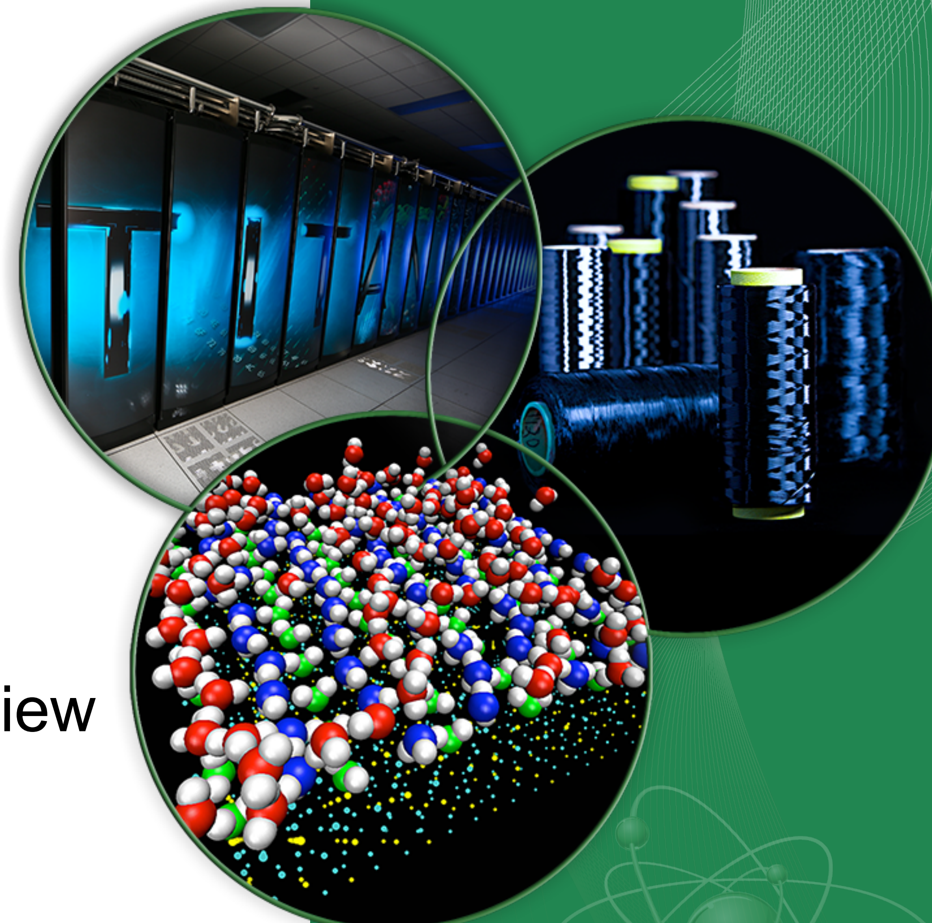
Analytical Methods for Calculating Experimental Correlations

B.J. Marshall
marshallwj@ornl.gov



NCSP Technical Program Review

Lawrence Livermore National Laboratory

March 18-19, 2015

OAK RIDGE
National Laboratory

Outline

1. Introduction
2. Sampler description and methods
3. Analysis of correlations
    1. LEU-COMP-THERM-042
    2. LEU-COMP-THERM-007, LEU-COMP-THERM-039
4. Other observations
5. Conclusions

Introduction

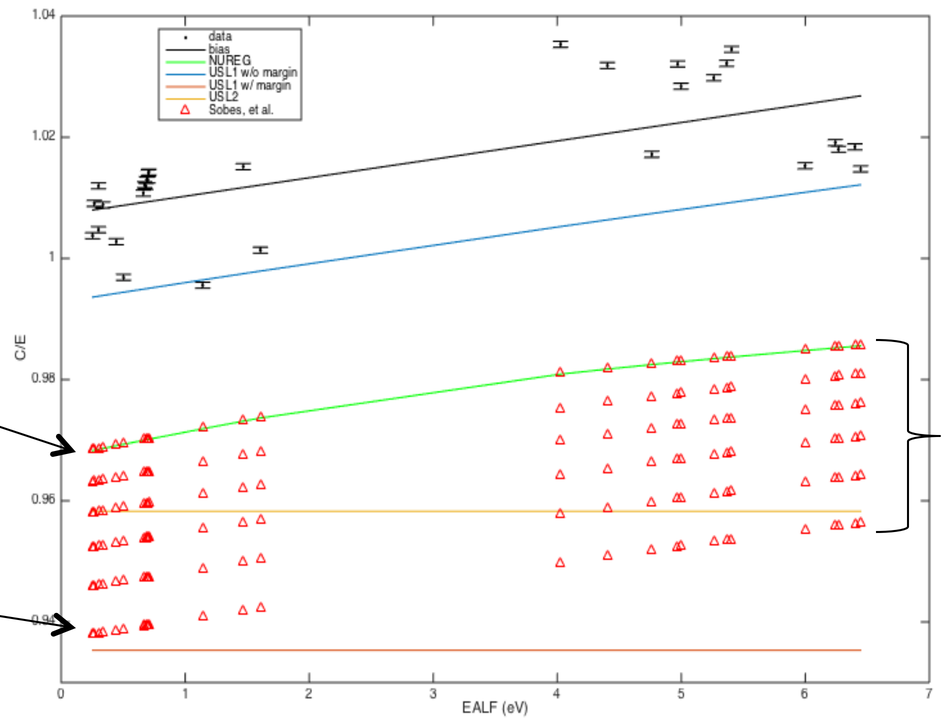
- Criticality safety validations typically use many cases from a single series of critical experiments
- The potential impact of correlations among the different cases has not been fully investigated
- Most methods currently used in validation assume independence of experiments
- Different methods, resulting in changed biases and potentially increased uncertainties, may be needed
- Analysis technique and results for 2 different sets of experiments presented

Importance of Experimental Correlations

- Potentially significant on USL
  - Vlad Sobes has derived a method for implementation in USLSTATS

USL ~0.97

USL <0.94



From Sobes et al., "Upper Subcritical Limit Calculations with Correlated Integral Experiments"

Assumed correlation coefficient ranges from 0 to 0.5

OAK RIDGE National Laboratory

Sampler Description and Methods

- New sequence available in SCALE 6.2 allowing for random sampling of essentially any input for almost any sequence
- Can be used to quantify uncertainties, or to calculate correlation coefficients
- User selects appropriate distribution and parameters for sampling composition and geometry inputs
  - Available distributions: uniform, normal, and beta
- Expressions can also be used to calculate perturbed inputs
- Perturbations applied to specified cases allowing identical realizations for shared characteristics

Sampler Description and Methods

Sampler input snippet:

```
read variable[wo_u235]
  distribution = normal
  value = 2.35 stddev = 0.00333
  minimum = 2.34  maximum = 2.36
  cases = Case1 Case2 Case3 Case4 Case5 Case6 Case7 end
end variable
```

- Defines variable named "wo_u235"
- Values sampled from a normal distribution
  - Average of 2.35 and standard deviation of 0.0033
  - Truncated at 2.34 and 2.36
- Sampled enrichment used in each of the 7 cases since they use the same fuel material

Sampler Description and Methods

- Independent parameters sampled uniquely in each case
  - Experiment temperature one possible example
- Three step process for executing calculations:
  1. Generate requested number of input realizations for each case
  2. Execute SCALE for all generated inputs
  3. Sampler post-processes KENO output files to generate Sampler outputs

Sampler Description and Methods

- Experimental correlations generated by Sampler in post-processing mode
- Random sampling to generate correlations based on theoretical developments of Buss, Hoefer, Neuber, and Schmid [PHYSOR 2010]
- Correlation coefficient calculated as covariance divided by product of standard deviations:

$$c_{i,j} = \frac{\mathrm{cov}(i, j)}{\sigma_i \sigma_j}$$

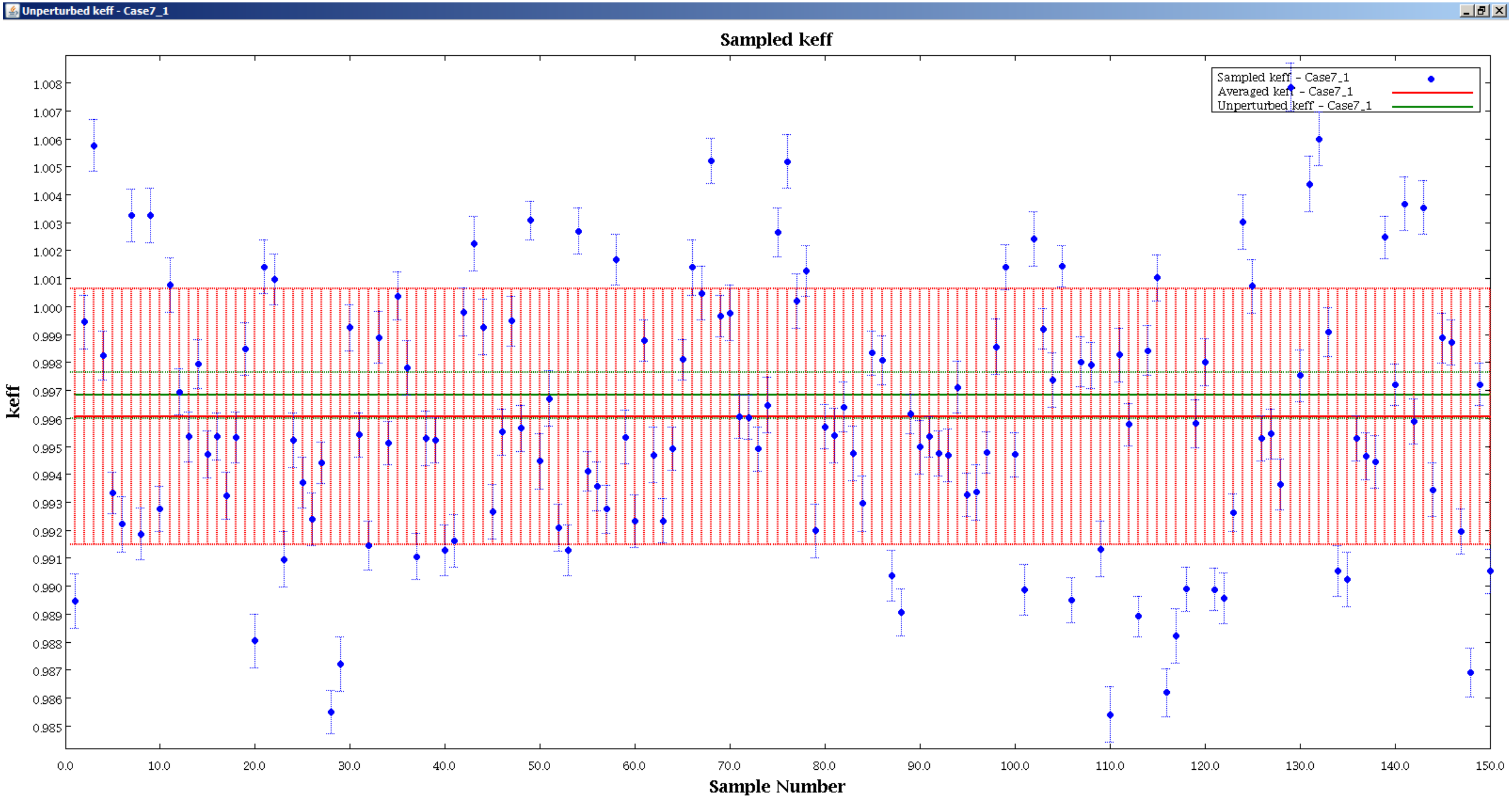
- Essential to include random uncertainty from both shared and unique features to generate accurate correlation

OAK RIDGE National Laboratory

Sampler Description – Output

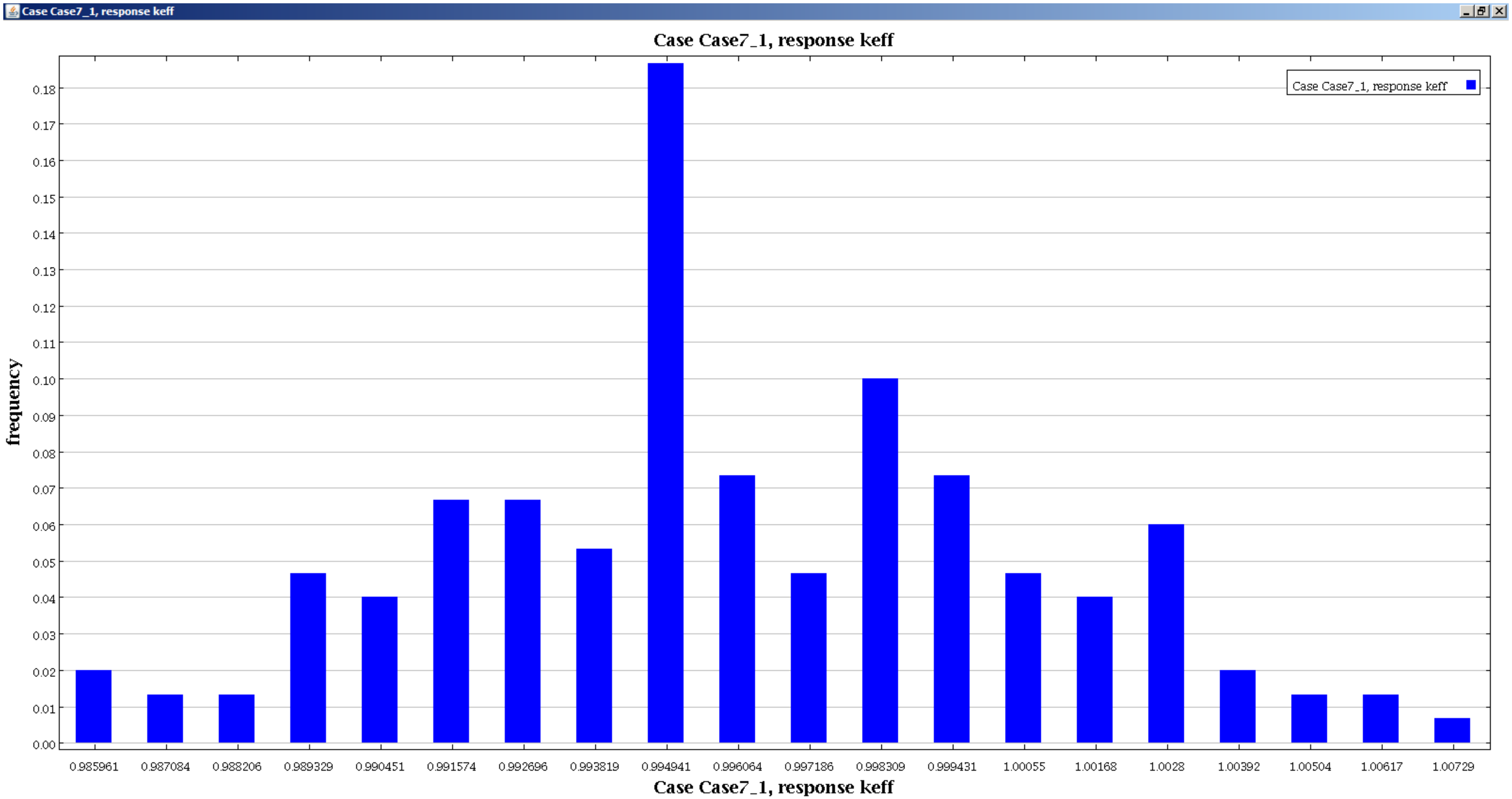
- Many outputs created
- Plots
  - Histograms
  - k_{eff} by sample
  - Requested parameters
  - Running averages
- Correlations among requested parameters
- Others

Sampler Description – Output
k_{eff} by sample, with average

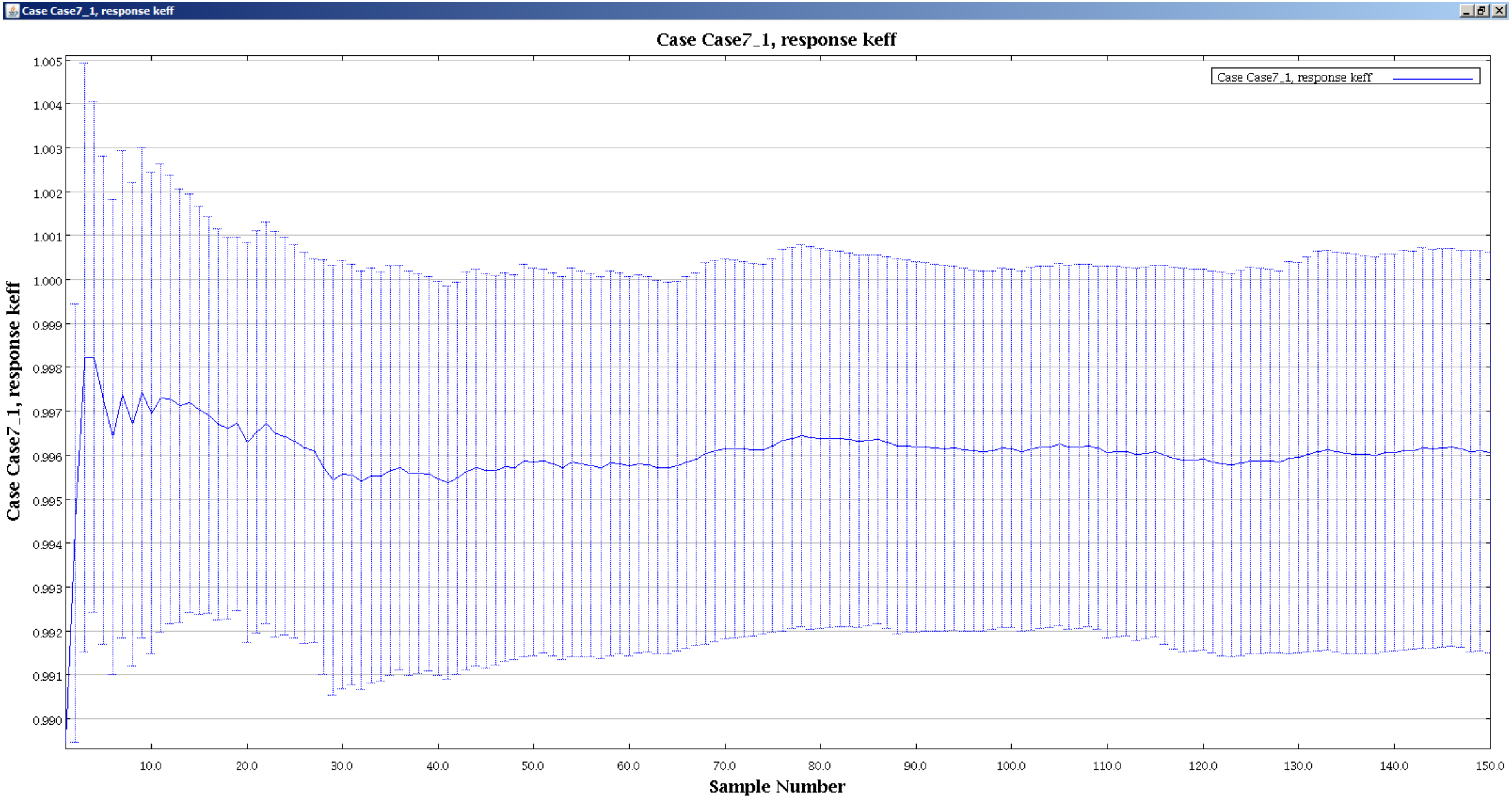


Oak Ridge National Laboratory

Sampler Description – Output Histogram of k_{eff} values



Sampler Description – Output
Running average of k_{eff}



OAK RIDGE National Laboratory

Analysis of LCT-042

- Dimension and material uncertainties described in Section 2 of IHECSBE evaluation
- Vast majority of input values are modified
  - Many sampled directly, others recalculated based on sampled inputs
- Assessment of shared or independent uncertainties needed
  - Poison panels clearly unique
  - Fuel material clearly shared
  - Other components unclear: reflecting wall, fuel rod pitch
  - Assumed to be shared unless otherwise specified

Analysis of LCT-042

- Distributions must be selected for sampling, but these are not specified in evaluation
- Most are assumed to be uniform because this seems likely to yield higher uncertainties and higher correlation coefficients which seems likely to be conservative
- Some parameters, notably enrichment, specifically mention standard deviation and are thus assumed to be normal
  - Obviously this is somewhat bogus as a uniform distribution has a standard deviation as well, so consider this an arbitrary choice
- No sensitivity study has been performed to examine the effect of these assumptions

Results

- Sampler created 275 realizations of each of the 7 cases (1925 total KENO jobs)
- Sampler generated correlation coefficients between 0.784 and 0.854

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Case 1	1	0.832	0.830	0.826	0.838	0.803	0.814
Case 2		1	0.831	0.831	0.854	0.810	0.829
Case 3			1	0.831	0.820	0.784	0.823
Case 4				1	0.837	0.791	0.806
Case 5					1	0.823	0.796
Case 6						1	0.803
Case 7							1

OAK RIDGE National Laboratory

Analysis of LCT-007 & LCT-039

- Analysis part of NEA Working Party on Nuclear Criticality Safety (WPNCS) Expert Group on Uncertainty Analysis for Criticality Safety Analysis (UACSA) benchmark for experimental correlations
- Problem specification controls sampled parameters and distributions
  - Fuel and pellet dimensions, fuel composition, fuel rod pitch, critical water height
- Work done in FY14 assumed fully correlated fuel pitch across all rods in all 20 cases considered
  - LCT-007-001 through -003 & all 17 cases in LCT-039

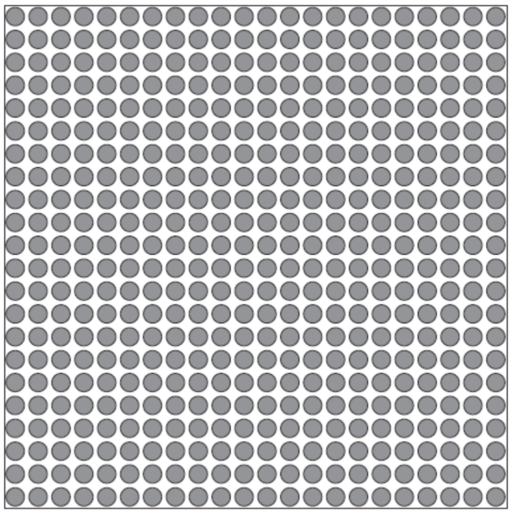
Results – LCT-007 & LCT-039

	7-1	7-2	7-3	39-1	39-2	39-3	39-4	39-5	39-6	39-7	39-8	39-9	39-10	39-11	39-12	39-13	39-14	39-15	39-16	39-17
7-1	1	0.124	0.080	0.999	0.999	0.999	0.999	0.998	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
7-2		1	0.095	0.120	0.122	0.122	0.124	0.127	0.124	0.125	0.121	0.124	0.126	0.123	0.123	0.124	0.124	0.122	0.123	0.127
7-3			1	0.081	0.082	0.083	0.083	0.095	0.094	0.080	0.081	0.087	0.087	0.080	0.080	0.080	0.085	0.087	0.083	0.086
39-1				1	0.999	0.999	0.999	0.998	0.998	0.999	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-2					1	0.999	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-3						1	0.999	0.999	0.998	0.999	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-4							1	0.999	0.998	0.999	0.999	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-5								1	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999	0.998	0.999
39-6									1	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.998	0.998
39-7										1	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-8											1	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-9												1	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-10													1	0.999	0.999	0.999	0.999	0.999	0.999	0.999
39-11														1	0.999	0.999	0.999	0.999	0.999	0.999
39-12															1	0.999	0.999	0.999	0.999	0.999
39-13																1	0.999	0.999	0.999	0.999
39-14																	1	0.999	0.999	0.999
39-15																		1	0.999	0.999
39-16																			1	0.999
39-17																				1

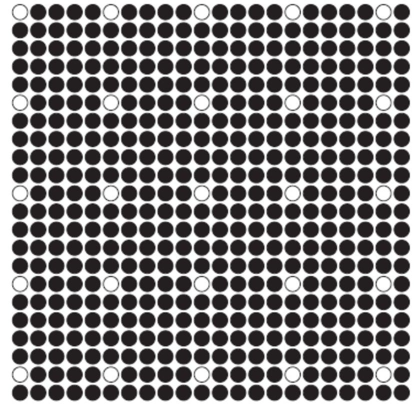
- LCT-007-001 & LCT-039 have a 1.26 cm pitch
- LCT-007-002 has a 1.6 cm pitch
- LCT-007-003 has a 2.1 cm pitch

LCT-007-001 & Selected LCT-039 Configurations

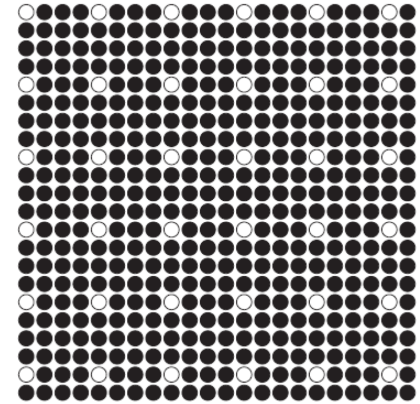
Case 1 22 x 22 x 1 Pitch = 1.26



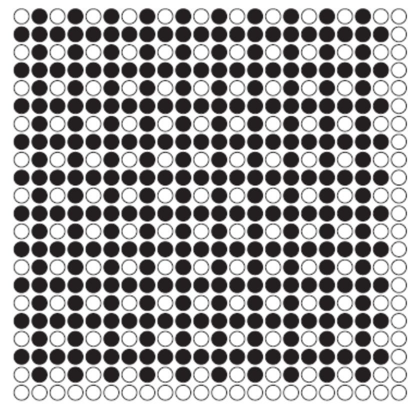
LCT-007



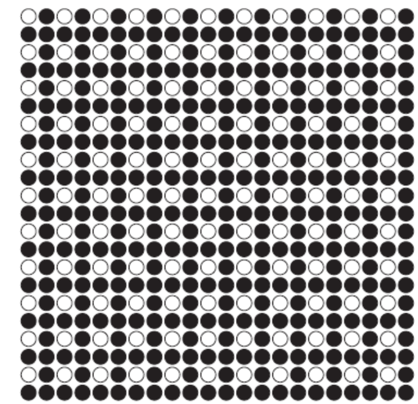
Case 1: 1 rod in 5 removed



Case 2: 1 rod in 4 removed



Case 5: 1 rod in 2 removed - array 21 x 21



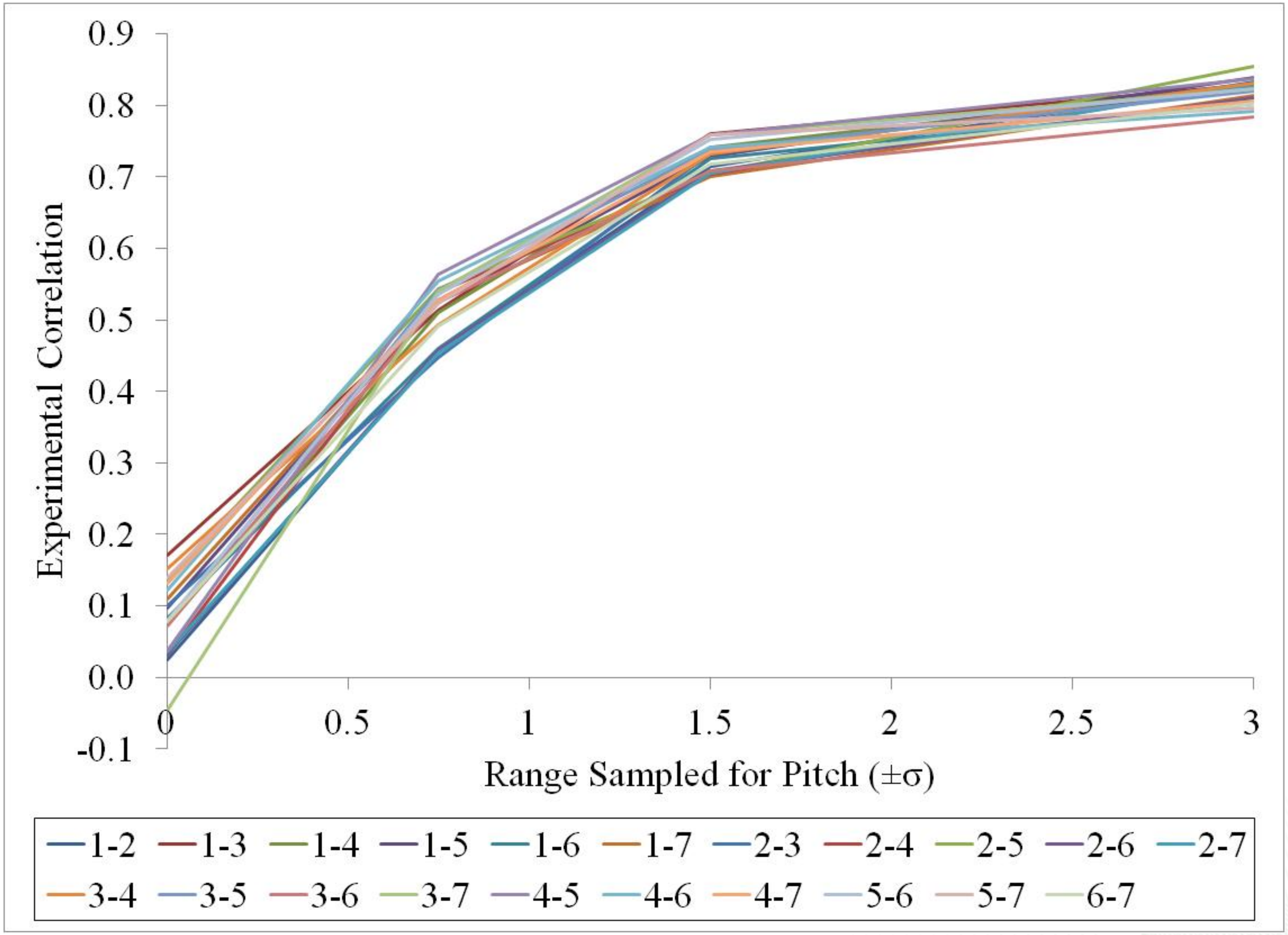
Case 6: 1 rod in 2 removed

LCT-039

Results

- Results from LCT-007 and LCT-039 indicate that *fuel rod pitch* is the controlling parameter, not shared fuel material
- Study performed on LCT-042 to investigate
  - New realizations created and correlations recalculated assuming ±1.5 and ±0.75 standard deviations and fixed rod pitches (fixed means no uncertainty)
    - Reducing uncertainty in a shared component should reduce correlation coefficient
    - Sensitivity of correlations to pitch sampling examined
    - Recall: Original concern largely driven by use of same fissile material in multiple experiments

Results


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
Experimental Correlation
0
0.5
1
1.5
2
2.5
3
Range Sampled for Pitch (±σ)
1-2
1-3
1-4
1-5
1-6
1-7
2-3
2-4
2-5
2-6
2-7
3-4
3-5
3-6
3-7
4-5
4-6
4-7
5-6
5-7
6-7

Other Observations

- Stochastic sampling to generate correlations presents many challenges
- Uncertainties are not known or provided for all parameters in Section 2 of IHECSBE evaluations
- Distributions of uncertain parameters is not addressed
- Details of experiment have been lost
  - Cd foil (LCT-042-005) mounted on something in some orientation
  - Pitch uncertainty from measurements of triangular pitch support plate, but LCT-042 has square pitch rods
- Collecting all sampling input is nearly impossible
- Treatment of pitch uncertainties (and defense of treatment to regulators) extremely important, yet unclear

Conclusions

- Stochastic sampling method to determine correlation coefficients can be performed using Sampler in SCALE 6.2
  – Also calculated uncertainties which can be compared to estimated uncertainties derived in Section 2 of IHECSBE evaluation
- Initial assumptions lead to high correlation coefficients
  – Fuel rod pitch appears to be controlling parameter for LCT experiments – *not* shared fissile material
- Different assumptions related to rod pitch variation reduce coefficients to less than 0.2
  – Fixed pitch results likely similar to totally random pitch variations
- Application of method to entire handbook is daunting

Future Work in FY15

- New models built for LCT-007 and LCT-039 with each pin modeled in separate unit
  - Supports new problem specification from UACSA
  - Utilized TemplateEngine in SCALE 6.2 Beta3
  - Pin-by-pin location sampling to establish correlation coefficients with varying degrees of independent pitch sampling
- Potentially revisit HST-001 correlations
  - Initially generated by student in Summer 2012
  - Incomplete specification believed to have impacted apparent correlations
  - First non-lattice case to be examined

Animation of first 75 realizations of LCT-007-001